

OPTIMAL DG PLACEMENT IN DISTRIBUTION NETWORKS WITH GENETIC ALGORITHM-BASED APPROACH AND TECHNO-ECONOMIC EVALUATION

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Abstract- In radial distribution grids, correctly locating appropriately sized Distributed Generation (DG) units can greatly enhance system performance. The most significant techno-economic advantages come from decreasing yearly economic losses, which involve deployment, operation, and maintenance costs as well as voltage fluctuations and power loss at the buses. The current issue is being evaluated with different multi-objective frameworks, and the Pareto-optimal solution is also discussed as the optimal compromise solution. When addressing a multi-objective optimization problem, specific equality and inequality constraints are also considered. This work concentrates on a unique multi-objective approach called whale optimization.

Utilizing genetic algorithms to solve problems with multiple objectives. In order to evaluate its efficiency, the proposed method is applied to IEEE-33 radial bus distribution systems for testing. This dissertation report also contains a comparison with other recent multi-objective algorithms like opposition-based chaotic Differential evolution (OCDE), Krill herd algorithm (KHA), and Power Loss Sensitivity Factor and Simulated Annealing (LSFSA). The proposed method may enhance power loss, annual economic

loss mitigation, and voltage profile improvement, as found in research.

Keywords: Optimal DG placement, Radial distribution network, Genetic algorithm, Multi-objective optimization, Techno-economic analysis, Voltage profile improvement

I. INTRODUCTION

The increasing demand for electricity, coupled with the need for sustainable energy solutions, has led to a significant transformation in the design and operation of power distribution networks. Distributed Generation (DG), which refers to the localized generation of electricity near the point of consumption, has emerged as a critical component in modern power systems. DG units offer numerous advantages, such as reducing transmission losses, improving voltage profiles, enhancing power quality, and integrating renewable energy sources like solar and wind. However, the placement and sizing of DG units in distribution networks are complex optimization problems that significantly impact both the technical performance and economic viability of the system.

Optimal placement of DG units requires a delicate balance between minimizing power losses, maintaining system stability,

improving voltage regulation, and maximizing economic benefits. Suboptimal placement can lead to increased losses, power quality issues, and underutilization of resources. This necessitates the development of robust optimization techniques capable of handling the multi-objective and constrained nature of the problem.

Genetic Algorithm (GA), a population-based metaheuristic inspired by the principles of natural selection, has gained widespread popularity for solving complex optimization problems in power systems. GA is particularly well-suited for DG placement due to its ability to explore large solution spaces and avoid local optima. By iteratively evolving a population of candidate solutions, GA identifies the optimal configuration of DG units to achieve the desired techno-economic objectives [1].

This study focuses on the optimal placement of DG units in distribution networks using GA, emphasizing a techno-economic analysis. The objectives include minimizing power losses, improving voltage profiles, and assessing the economic feasibility of DG integration. The proposed methodology incorporates system constraints, such as power flow limits, voltage regulations, and cost considerations, to ensure practical and effective solutions.

Through detailed simulations and case studies, the research evaluates the performance of the GA-based approach in various scenarios, highlighting its effectiveness in achieving technical improvements and economic gains. The outcomes of this study are expected to contribute to the development of efficient, resilient, and sustainable distribution networks, facilitating the integration of distributed energy resources in a cost-effective manner [2].

Classification of Electric Power Distribution Network Systems

The typical electric power system network is classified into three parts;

- Generation
- Transmission
- Distribution

There are places called power plants where electricity is made. It is normal for power plants to be located a long way from where the loads are. These are the reasons why the transmission line is used to send electricity over a long distance. In order to cut down on the losses that happen during transfer, high voltage electricity is used in a transmission line. In addition, the power level drops in the middle of the load. Power gets to the load through a device called a distribution system.[3]

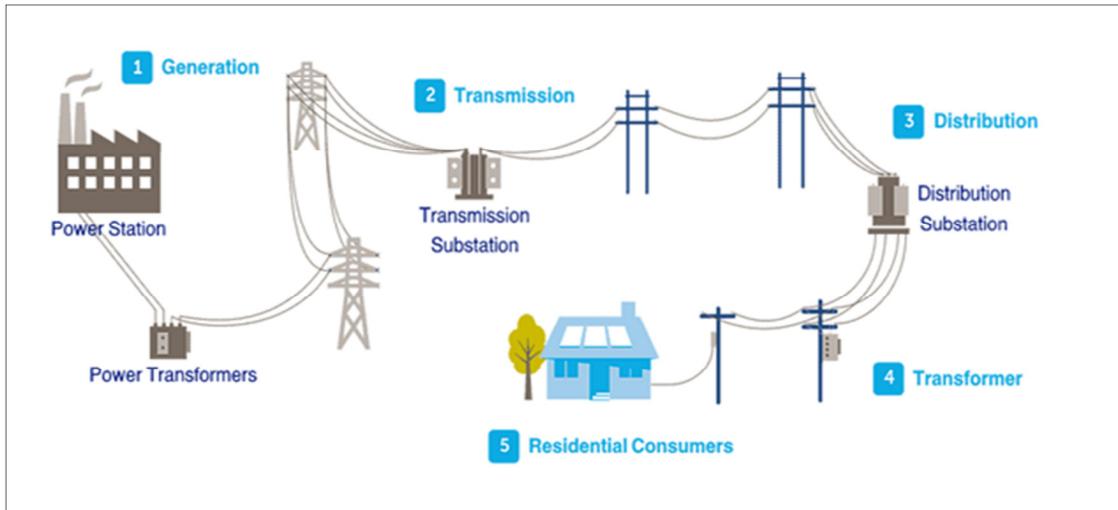


Figure 1. Electric Power Distribution Network Systems

II. METHODOLOGY

Optimization & Bio-Inspired Computational Intelligence (CI) Techniques

Essentially, CM is a complex issue involving numerous variables that can be solved using optimization algorithms. Modern power systems face intricate challenges because of their complicated architecture, large geographical variations, and unpredictable factors. Continuous improvements have been made in metaheuristics optimization algorithms to decrease computational time, enhance solution quality, and tackle larger instances. Hybridizing techniques are intriguing for their adaptability to a diverse range of issues, making them particularly

noteworthy. Swarm intelligence and metaheuristics algorithms are categorized as bio-inspired algorithms that have an extensive track record in addressing optimization problems.

During the optimization of a specific problem, Bio-inspired optimization algorithms like GA and PSO have various behavioral parameters that influence their effectiveness. Efficient optimization is promoted by a carefully chosen set of parameters. Adjusting parameters by hand is a time-consuming process. Bio-inspired optimization algorithms demonstrate the ability to produce optimal results in scientific applications.

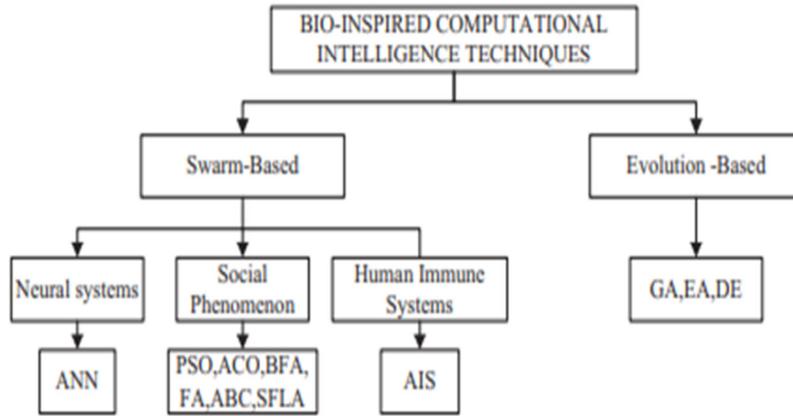


Figure 2. Classification of Bio-Inspired CI Techniques

IEEE 33-Bus System

The IEEE 33-bus system is a standard radial distribution network widely used in research for testing algorithms related to load flow analysis, optimization, and distributed generation placement. It consists of 33 buses, 32 branches, and operates with a base voltage of 12.66 kV and base apparent power of 100 MVA. The network starts from a single substation (source) and supplies power downstream to various loads. It has a total real power

demand of 3.715 MW and a reactive power demand of 2.3 MVar. Due to its simplicity and practical relevance, it serves as an effective benchmark for studying power loss minimization, voltage stability improvement, and the integration of renewable energy sources in distribution systems.

Load bus: Here at the load bus, both the reactive and real forces are shown. Neither the voltage nor the phase angle is defined. This bus is not connected to any engines.

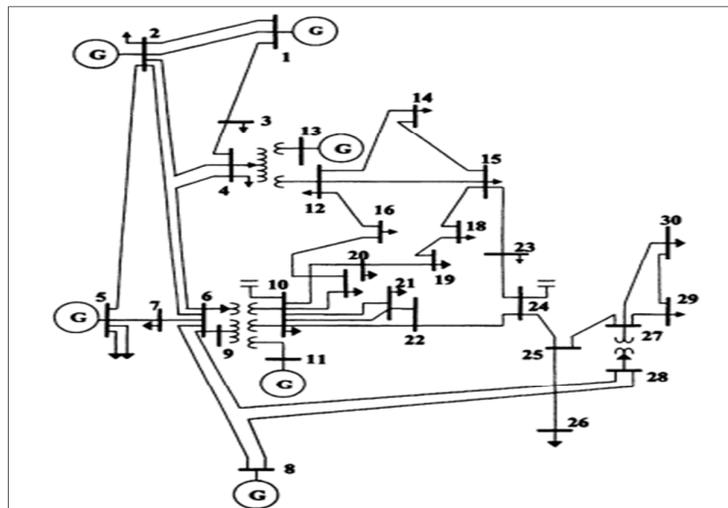


Figure 3. IEEE 30 Bus System

Slack Bus: The voltage-controlled bus is another name for the generator bus. This

bus has another name. In this part of the standard, the real power (P_g) and the

voltage magnitude that match the generator voltage are given. In the equations for line flow, the reactive power generation (also called Q_g) and the voltage phase angle are the unknown parameters. This kind of bus is also called a Slack Bus or a Swing Bus. In this bus, it is assumed that the size of the voltage and the phase angle are factors that are known. P_g , which stands for "real power," and Q_g , which stands for "reactive power," are both thought to be unknown factors.

Optimization Algorithm

Distributed Generation (DG) plays a crucial role in modern power distribution systems by improving efficiency, reducing power losses, and supporting renewable energy integration. However, the placement and sizing of DG units are complex optimization problems due to the nonlinear and multi-objective nature of power flow dynamics. This section presents two robust optimization techniques — Genetic Algorithm (GA) and Cuckoo Search Optimization (CSO) — for determining the optimal placement and sizing of DG units in the IEEE 33-bus distribution system.

Problem Formulation

The optimization objective includes:

Minimizing Active Power Losses: Reducing line losses to enhance overall system efficiency.

Improving Voltage Profiles: Ensuring voltage levels remain within acceptable limits across all buses.

Techno-Economic Analysis: Balancing the technical benefits with the cost of DG installation and operation.

The constraints include:

Voltage limits:

$$V_{\min} \leq V_i \leq V_{\max} \quad V_{\min} \leq V_i \leq V_{\max}$$

for all buses.

Power flow balance: Ensuring power generation meets load demand.

DG capacity limits: DG units must operate within specified capacity ranges.

Genetic Algorithm (GA) for DG Placement

GA is a metaheuristic inspired by natural evolution, effectively handling multi-objective optimization problems. Its steps for DG placement in the IEEE 33-bus system are:

Initialization: Generate an initial population of candidate solutions, each representing DG placement and sizing combinations.

Fitness Evaluation: Calculate the fitness of each solution based on objectives like power loss minimization and voltage improvement.

Selection: Select parent solutions based on fitness, using techniques like tournament or roulette-wheel selection.

Crossover and Mutation: Generate offspring by combining parents and introducing small mutations to enhance diversity.

Replacement: Form a new population by replacing less-fit solutions with better-performing offspring.

Termination: Stop the algorithm once convergence criteria, such as a maximum number of iterations or minimal fitness improvement, are met.

Cuckoo Search Optimization (CSO) for DG Placement

CSO is inspired by the brood parasitism behavior of cuckoos. It combines Lévy flight-based random search with efficient global exploration. The steps for DG placement in the IEEE 33-bus system are:

Initialization: Generate an initial population of solutions (nests), each representing DG placement and sizing.

Fitness Evaluation: Evaluate the fitness of nests based on power loss minimization and voltage profile improvement.

Lévy Flight Update: Perform a random walk using Lévy flights to explore the search space and create new solutions.

Selection and Abandonment: Retain the best solutions and replace the worst-performing nests with new random solutions.

Convergence: Repeat steps 2-4 until convergence criteria, such as maximum iterations or minimal improvement, are satisfied.

Implementation in IEEE 33-Bus System

System Modeling: Model the IEEE 33-bus distribution system, including line and load data.

Input Data: Define DG parameters (size and cost), system constraints, and algorithm settings.

Algorithm Execution:

Run GA and CSO separately to determine the optimal DG placement and sizing.

Compare performance metrics such as power loss reduction, voltage profile improvement, and computational efficiency.

Comparative Analysis

GA: Offers strong global search capabilities and is effective in exploring diverse solutions but may converge slowly for complex problems.

CSO: Provides faster convergence due to Lévy flight's exploratory nature but may require fine-tuning of parameters for optimal results.

III. RESULTS

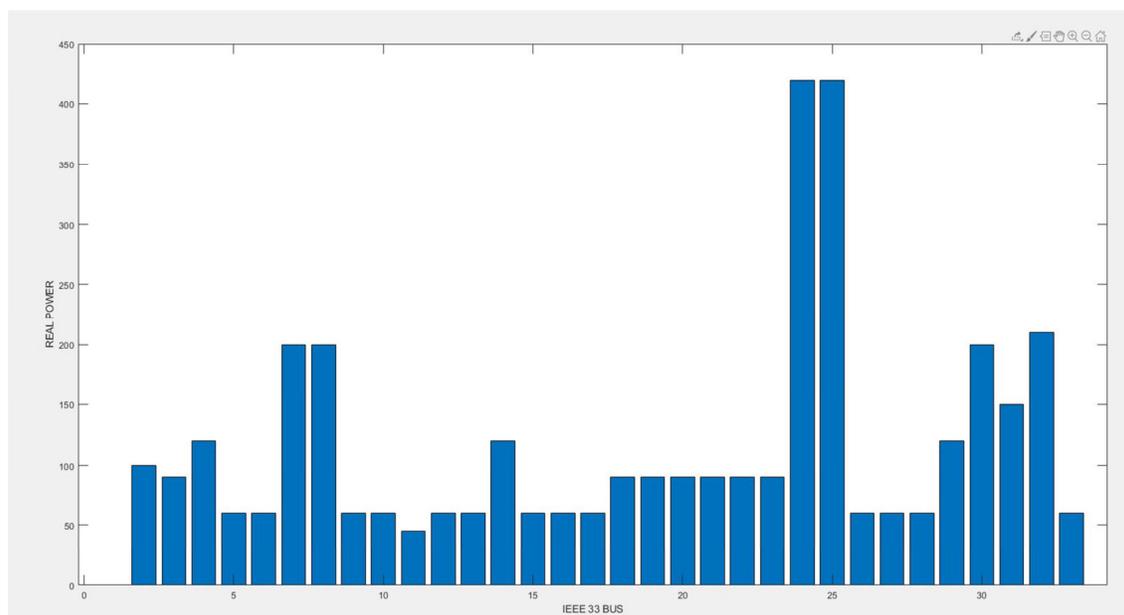


Figure 4. IEEE 33 Bus Real Power

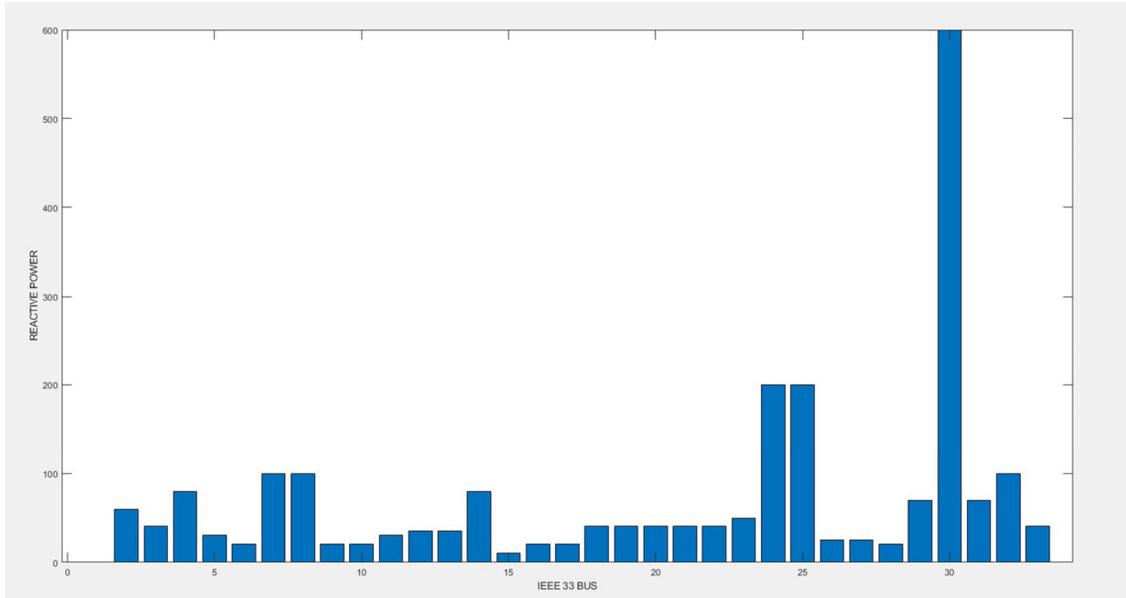


Figure 5. IEEE 33 Reactive Power

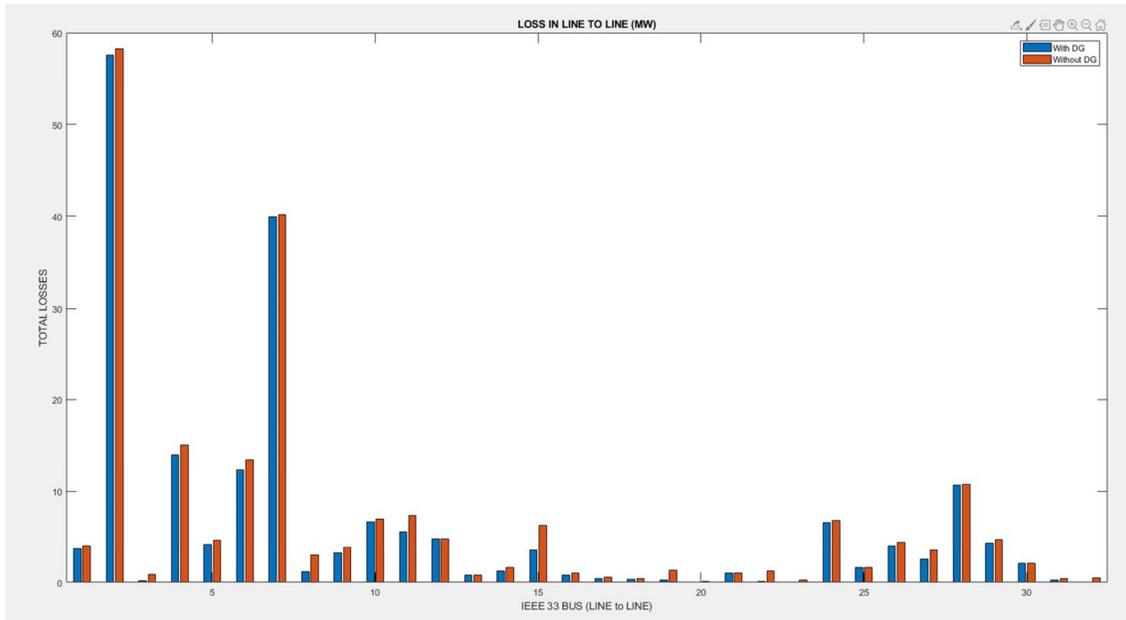


Figure 6. IEEE 33 Line to Line Total Losses

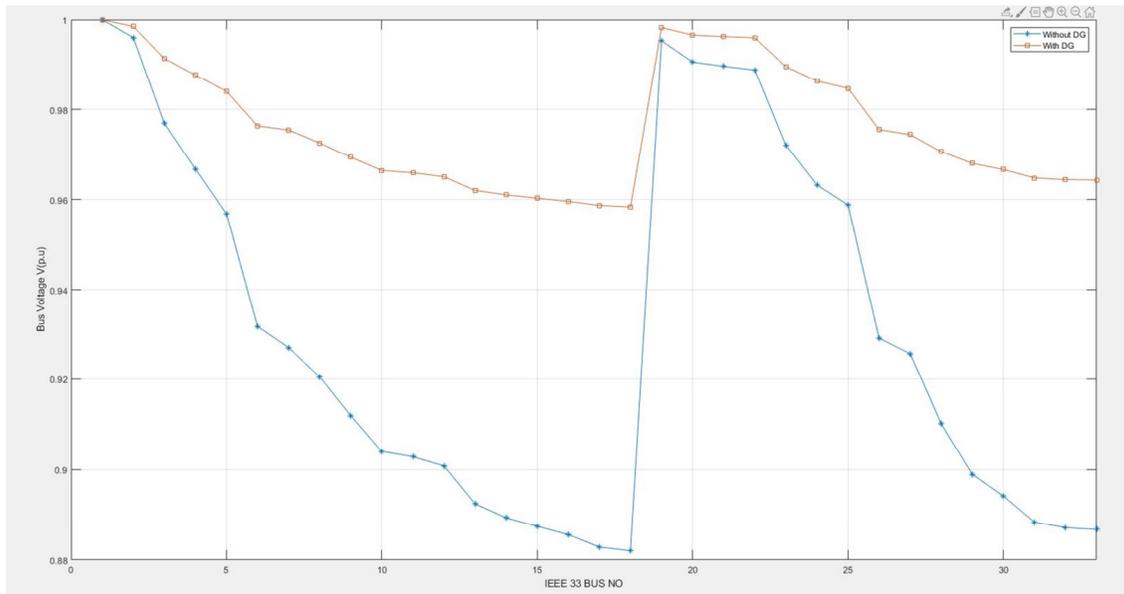


Figure 7. IEEE 33 Bus Voltage

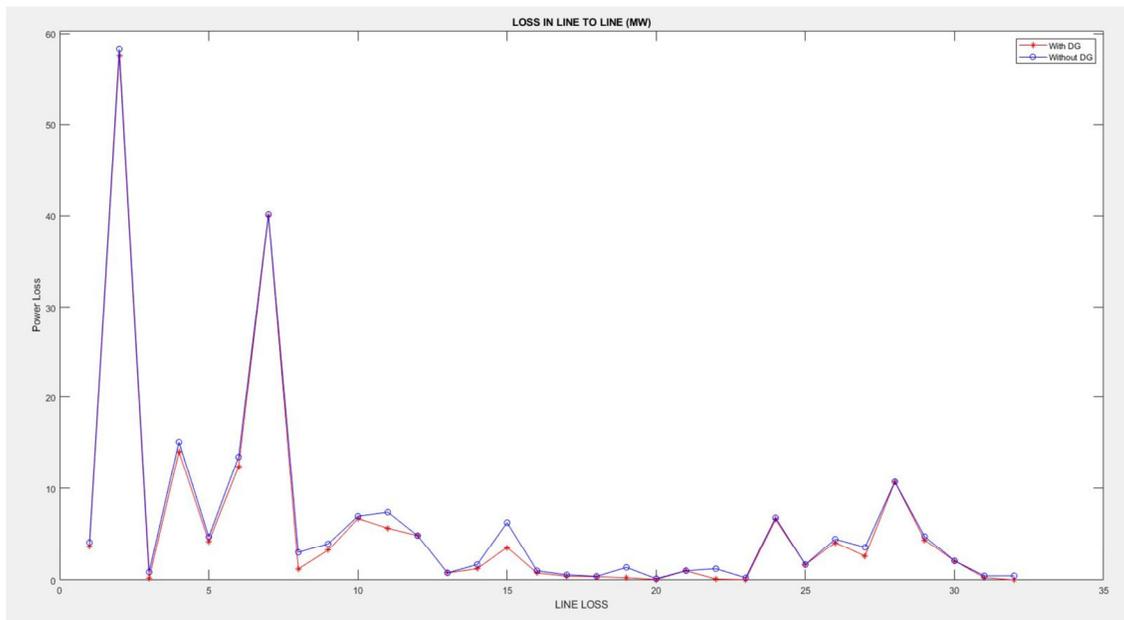


Figure 8. IEEE 33 Line to Line Losses

	With DG	Without DG
1	3.6719	4.1019
2	57.6172	58.3126
3	0.1897	0.8584
4	14.0058	15.0956
5	4.2069	4.7141
6	12.3897	13.4590
7	39.9708	40.1649
8	1.1950	2.9935
9	3.2277	3.9387
10	6.7083	6.9647
11	5.6524	7.4117
12	4.8458	4.8482
13	0.7705	0.7743
14	1.2309	1.6776
15	3.5311	6.2686
16	0.7695	1.0113
17	0.4197	0.5676
18	0.3669	0.4054
19	0.2527	1.3693
20	0.0700	0.1486
21	0.9999	1.0165
22	0.1090	1.2264
23	0.0443	0.2468
24	6.6116	6.8054
25	1.6586	1.6739
26	4.0711	4.4592
27	2.5862	3.5621
28	10.6907	10.7167
29	4.3649	4.7481
30	2.0670	2.0827
31	0.2640	0.4553
32	0.0159	0.4623

Figure 9. Line to Line Voltage with and without DG

Command Window Output

```

WITHOUT DG Solution
=====
=====
Bus Voltage Angle -----Load-----
No. Mag. Degree kW kVAr
=====
=====

```

```

1 1.0000 0.0000 0.0000 0.0000
2 0.9960 0.0004 100.0000 60.0000
3 0.9770 0.0024 90.0000 40.0000
4 0.9668 0.0040 120.0000 80.0000

```

```

5 0.9568 0.0057 60.0000 30.0000
6 0.9318 0.0036 60.0000 20.0000
7 0.9271 -0.0020 200.0000 100.0000
8 0.9205 -0.0012 200.0000 100.0000
9 0.9119 -0.0032 60.0000 20.0000
10 0.9040 -0.0048 60.0000 20.0000
11 0.9028 -0.0047 45.0000 30.0000
12 0.9008 -0.0044 60.0000 35.0000
13 0.8924 -0.0068 60.0000 35.0000
14 0.8894 -0.0089 120.0000 80.0000
15 0.8874 -0.0098 60.0000 10.0000

```

16	0.8856	-0.0105	60.0000	20.0000	2	0.9985	0.0010	100.0000	60.0000
17	0.8828	-0.0125	60.0000	20.0000	3	0.9913	0.0056	90.0000	40.0000
18	0.8820	-0.0127	90.0000	40.0000	4	0.9876	0.0084	120.0000	80.0000
19	0.9953	0.0001	90.0000	40.0000	5	0.9840	0.0111	60.0000	30.0000
20	0.9906	-0.0015	90.0000	40.0000	6	0.9764	0.0169	60.0000	20.0000
21	0.9896	-0.0019	90.0000	40.0000	7	0.9755	0.0173	200.0000	100.0000
22	0.9888	-0.0024	90.0000	40.0000	8	0.9726	0.0188	200.0000	100.0000
23	0.9722	0.0016	90.0000	50.0000	9	0.9694	0.0203	60.0000	20.0000
24	0.9632	-0.0005	420.0000	200.0000	10	0.9665	0.0218	60.0000	20.0000
25	0.9588	-0.0015	420.0000	200.0000	11	0.9660	0.0221	45.0000	30.0000
26	0.9292	0.0046	60.0000	25.0000	12	0.9651	0.0225	60.0000	35.0000
27	0.9257	0.0061	60.0000	25.0000	13	0.9620	0.0240	60.0000	35.0000
28	0.9101	0.0085	60.0000	20.0000	14	0.9611	0.0245	120.0000	80.0000
29	0.8989	0.0107	120.0000	70.0000	15	0.9603	0.0247	60.0000	10.0000
30	0.8941	0.0134	200.0000	600.0000	16	0.9596	0.0250	60.0000	20.0000
31	0.8884	0.0114	150.0000	70.0000	17	0.9587	0.0254	60.0000	20.0000
32	0.8871	0.0109	210.0000	100.0000	18	0.9584	0.0256	90.0000	40.0000
33	0.8867	0.0107	60.0000	40.0000	19	0.9982	0.0011	90.0000	40.0000
=====					20	0.9965	0.0018	90.0000	40.0000
=====					21	0.9962	0.0020	90.0000	40.0000
Total			3715.0000	2300.0000	22	0.9960	0.0021	90.0000	40.0000
=====					23	0.9895	0.0065	90.0000	50.0000
=====					24	0.9863	0.0081	420.0000	200.0000
WITH DG Solution					25	0.9847	0.0089	420.0000	200.0000
=====					26	0.9756	0.0178	60.0000	25.0000
=====					27	0.9745	0.0191	60.0000	25.0000
Bus	Voltage	Angle	-----Load-----		28	0.9707	0.0238	60.0000	20.0000
No.	Mag.	Degree	kW	kVAr	29	0.9681	0.0272	120.0000	70.0000
=====					30	0.9667	0.0293	200.0000	600.0000
=====									
1	1.0000	0.0000	0.0000	0.0000					

31	0.9648	0.0303	150.0000	70.0000	23	856.7805	585.4287	4.2069
32	0.9644	0.0306	210.0000	100.0000	2.8745			
33	0.9643	0.0306	60.0000	40.0000	4	120.0000	80.0000	
=====					3-2574.2417-1311.0346			14.0058
=====					13.7538			
Total			3715.0000	2300.0000	5	2446.0545	1245.8126	12.3897
=====					12.9314			
=====					5	60.0000	30.0000	
Line Flow and Losses					4-2420.6647-1232.8812			12.3897
=====					12.9314			
=====					6	2026.1028	1749.0289	39.9708
=					45.7270			
--Line-- Power at bus & line flow --					6	60.0000	20.0000	
Line loss--					5-1973.1319-1703.3019			39.9708
from	to	kW	kVAr	kW	45.7270			
kVAr					7	237.1261	783.8336	1.1950
=====					3.9503			
=====					26	1151.6250	586.5912	3.2277
=					1.6441			
1	0.0000	0.0000			7	200.0000	100.0000	
2	4167.3382	2124.3481	3.6719		6	-235.9311	-779.8833	1.1950
8.4987					3.9503			
2	100.0000	60.0000			8	940.2626	310.7334	6.7083
1-4150.6664-2115.8495			3.6719		2.2169			
8.4987					8	200.0000	100.0000	
3	3694.8645	1881.9077	57.6172		7	-933.5543	-308.5165	6.7083
35.9675					2.2169			
19	269.5555	257.2282	0.1897		9	609.1474	437.6399	5.6524
0.1810					4.0609			
3	90.0000	40.0000			9	60.0000	20.0000	
2-3624.2474-1845.9402			57.6172		8	-603.4950	-433.5789	5.6524
35.9675					4.0609			
4	2601.2476	1324.7884	14.0058		10	557.5535	395.2008	4.8458
13.7538					3.4348			

10	60.0000	20.0000		17	81.7588	109.1598	0.2527
							0.3373
9	-552.7077	-391.7660	4.8458	17	60.0000	20.0000	
3.4348							
11	591.0520	195.4139	0.7705	16	-81.5062	-108.8225	0.2527
0.2547							0.3373
11	45.0000	30.0000		18	74.7211	58.5928	0.0700
							0.0549
10	-590.2815	-195.1592	0.7705	18	90.0000	40.0000	
0.2547							
12	540.6324	178.7668	1.2309	17	-74.6512	-58.5379	0.0700
0.4070							0.0549
12	60.0000	35.0000		19	90.0000	40.0000	
11	-539.4015	-178.3598	1.2309	2	-269.3658	-257.0472	0.1897
0.4070							0.1810
13	381.9155	300.4853	3.5311	20	209.6996	188.9555	0.9999
2.7782							0.9010
13	60.0000	35.0000		20	90.0000	40.0000	
12	-378.3844	-297.7071	3.5311	19	-208.6997	-188.0545	0.9999
2.7782							0.9010
14	223.8422	294.6402	0.7695	21	115.5820	135.0291	0.1090
1.0129							0.1273
14	120.0000	80.0000		21	90.0000	40.0000	
13	-223.0727	-293.6273	0.7695	20	-115.4730	-134.9018	0.1090
1.0129							0.1273
15	194.7403	173.3222	0.4197	22	51.9061	68.6297	0.0443
0.3735							0.0586
15	60.0000	10.0000		22	90.0000	40.0000	
14	-194.3207	-172.9487	0.4197	21	-51.8618	-68.5712	0.0443
0.3735							0.0586
16	174.7932	127.6461	0.3669	23	90.0000	50.0000	
0.2679							
16	60.0000	20.0000		3	-852.5736	-582.5542	4.2069
							2.8745
15	-174.4264	-127.3782	0.3669	24	720.1397	568.6537	6.6116
0.2679							5.2208
				24	420.0000	200.0000	

23 -713.5281 -563.4329	6.6116	30 -320.1312 -316.3858	2.0670
5.2208		2.0428	
25 359.0271 280.9307	1.6586	32 185.5376 216.2514	0.2640
1.2978		0.3077	
25 420.0000 200.0000		32 210.0000 100.0000	
24 -357.3685 -279.6329	1.6586	31 -185.2737 -215.9438	0.2640
1.2978		0.3077	
26 60.0000 25.0000		33 36.0981 56.1267	0.0159
6-1148.3973 -584.9472	3.2277	0.0248	
1.6441		33 60.0000 40.0000	
27 1090.1169 555.0314	4.0711	32 -36.0821 -56.1019	0.0159
2.0728		0.0248	
27 60.0000 25.0000		=====	
26-1086.0458 -552.9586	4.0711	=====	
2.0728		=	
28 926.6003 816.9657	2.5862	Total loss	194.5756
13.7421		178.0596	
28 60.0000 20.0000		Best_locations =	
27 -911.0141 -803.2237	2.5862	13 25 28 31	
13.7421		DG POWER(W) SIZE at 13 BUS	
29 870.3325 758.2131	10.6907	LOCATION(W):2085.7586	
9.3135		DG POWER(W) SIZE at 25 BUS	
29 120.0000 70.0000		LOCATION(W):521.4396	
28 -859.6418 -748.8996	10.6907	DG POWER(W) SIZE at 28 BUS	
9.3135		LOCATION(W):1042.8793	
30 817.1523 416.2243	4.3649	DG POWER(W) SIZE at 31 BUS	
2.2233		LOCATION(W):260.7198	
30 200.0000 600.0000		***** GENERATION	
29 -812.7873 -414.0010	4.3649	*****	
2.2233		TOTAL DG-SIZE(MW) in IEEE 33 bus	
31 322.1982 318.4286	2.0670	system : 3.9108	
2.0428		TOTAL DG POWER	
31 150.0000 70.0000		GENERATION(MW) : 3.9096	

***** LOAD

PLI Total Load power(MW) : 3.7150

***** LOSS

TOTAL LOSS LINE TO LINE(KW) :
194.5756

IV. CONCLUSION

In this dissertation, an enhanced GA - Cuckoo Search technique is introduced for positioning optimally sized DGs in ideal locations. In order to demonstrate its efficiency, the proposed technique was evaluated on various test systems for radial distribution, such as the IEEE-33 bus systems. Two goals which include loss of power and yearly economic loss, alongside a multiple objective approach.

The main goal of assessing these objectives is to decrease the total annual economic loss, minimize real power loss, and improve the voltage profile to optimize overall annual savings. When appropriately sized DGs are placed in suitable locations, there is a notable decrease in annual economic loss and real power loss, leading to an enhanced voltage profile. There has been a significant rise in the yearly economic gain due to a decrease in the annual economic loss. When comparing the outcomes of the

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recommended method with those of alternative approaches, it becomes apparent that the proposed method yields superior results.

When evaluating the MOWOA method against algorithms like OCDE, KHA, and LSFSA, it is clear that it performs exceptionally well in all scenarios and is able to attain higher levels of accuracy and variety.

The following inferences can be drawn:

- The proposed method is appropriate for determining optimal placements and sizes of DG in a distribution network.
- The multi-objective whale optimization method is employed for optimal integration of DGs, leading to a decrease in total real power losses and cost of energy losses.
- According to numerical results, the proposed method outperforms other methods in the literature and is considered satisfactory.
- WOA has found an improved answer for the optimal positioning of many Showing strong uniformity and fast convergence traits, DGs in radial distribution systems stand out.

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